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COMMUNICATION VIA ELECTRIC POWER-TRANSMISSION LINES OF USSR

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[Note: Numbers in parentheses refer to the bibliography.]

In 1922, Prof. A. A. Chernyshev (1) conducted successful tests on a 110-kv line between Khabarovsk and Moscow and obtained satisfactory telephone communication at a distance of 170 km with a transmitter power of 7 watts. From 1924 to 1930, GPTI produced about 30 stations (using Prof. Chernyshev's system) for use on the USSR power system.

In 1929-1930, Engineer V. A. D'yakov (now Doctor of Technical Sciences, Professor) and a group of collaborators in TsLPS (Central Laboratory of Communications) attempted to develop his complex problems of high-frequency communication over the electric power lines (2). As a result of these works, individual plants began to produce stations of the DPK-20, DPK-27 and DPK-38 type; various auxiliary equipment, ED, KU, FF; high-voltage condensers, and others. Up to 1941 the "Sevkabel" plant made possible communication via the power system with its production of high-frequency feeder cables. At the beginning of the war, the total length of high-frequency-communication channels on electric transmission lines was about 5,000 km in spite of the fact that tens of high-voltage lines were equipped with high-frequency links. In 1941, Engineer Kruglyakov in the "Krasnaya Zarya" plant finished the work on shields for high-frequency systems (3).

The doctors' theses of V. A. D'yakov and V. I. Ivanov were concerned with the theory of high-frequency communication over power lines. Original works in the field of high-frequency-line shields and research of circuit parameters were carried out by Engineer Ye. A. Karpovich (k).

Basic Technical Data of High-Frequency Channels on Electric Transmission Lines

Communication over high-voltage lines is distinguished from other means by (a) the use of high frequency to maintain the stability of the power system in controlling telephone communications, telemechanics, and shielding, and (b) the necessity of adapting high-frequency apparatus to working conditions of high-voltage lines which are constructed primarily for the transmission of electric power.

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The need for filtering industrial frequency of 50 cycles at voltages of 100-200 kv and currents of 400-800 amp in normal operation and 20,000-30,000 amp [sic] in emergency operation and the filtering of communication frequencies led to a significant separation of frequencies (the lower limit of high-frequency communication over electrical transmission lines is around 50 kc). It has also led to the design of special equipment for connections and operations -- coupling condensers with compensator arrangements or coupling filters and resonance filters (sometimes these are called high-frequency limits).

The upper frequency limit was 150 kc in the USA and 200 kc in Europe; at present it has been extended to 300 kc. This limit depends on the attenuation level of the high-frequency channel and interference from radio stations.

Coupling condensers and resonance filters are very insecure, expensive, and are deficient components of equipment for high-frequency communication over transmission lines. The capacitance of condensers on 120 kv is 2,200 or 4,400 micromicrofarads, the inductance of the power choke coils along which the full current of the line load flows is between 0.1-0.2 millihenries. Changing of these parameters or increasing the number of circuit components is very difficult. This limits the selection of systems and circuit parameters for high-frequency channels on transmission lines.

Widening the bands of the transmission frequencies (for example, for the transmission of telemechanic signals along the above-voice frequency channel) is difficult due to the necessity of increasing the inductance of the power-line coils of the resonance filters. At present 100-200 kg of copper are used to manufacture such a coil. Increasing the inductance not only makes necessary a greater expenditure of copper, but also brings about a series of additional difficulties in regard to dimensions, strengthening and insulating the components.

The interference levels in high-voltage lines depends on the corona effects, leakage, particle charges, and also on the extent of switching-in at various points of the circuit. These levels are much higher than on regular communication lines. In the operating range at a band width of 5 kc, the average interference level on 110-kv lines is around 4.5 nep, and on 220-kv lines about 3.5 nep. In emergency operation (with the high voltage removed from the line) the interference level is decreased 6 to 7 nep. Attenuation of the communication channel along a 150-km line with a single-phase circuit is calculated by an empirical formula, established by the author in 1939 as the result of measurements on a series of lines (5).

Attenuation of the communication channel along a 150-km line having two substations is around 5 nep at a frequency of 196 kc. Without substation intervals, the channel attenuation at the same frequency would decrease to 3.5, and at a frequency of 49 kc to 2.15 nep.

The length of the communication channels is determined by the structure of the distribution system and configurations of the high-voltage circuit. It varies within wide limits from several tenths to several hundred kilometers. Most of the high-frequency channels are from 100-200 km long, with not more than two substation intervals at lengths of 200 km.

Their attenuation levels vary from 1.85 nep for 50 kc and 100 km length without branch circuits to 6.8 nep for 300 kc and 200 km with two branch circuits.

According to the norms for long-distance communication, the signal levels should be higher by 4.75 nep than the interference levels. However, on transmission lines it is difficult to maintain the norm. From the experience of USSR power systems, it can be established that on the basis of a provisional norm for high-frequency communication along transmission lines, the signal level is 3.5 nep above the interference level, which corresponds to an absolute signal level of 1.25 nep for a 110-km line. In the transmission of a carrier and two side bands at 100 percent modulation, the carrier level is equal to the side-band frequency level, i.e., it should be no lower than -1.25 nep.

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At a 40 percent modulation, the carrier level should be 0.9 nep higher, i.e., equal to -0.35 nep (for the transmission of a single side band, the level should be still higher by 0.7 nep, i.e., in the given case it would be +0.35 nep). If we assume that the high-frequency communication system is going to transmit 5 nep without amplification at a modulation coefficient of 0.4, then the carrier levels of the transmitter output should be equal to $5 - 0.35 = 4.65$ nep which corresponds to a power of 11 watts in a telephone circuit.

A very important characteristic is the low value of the cross-talk attenuation between high-voltage lines, being around 2 nep for lines going in one and the same substation.

Since, between the transmitter of one channel and receiver of another, there should be an attenuation of the order of 14.5 nep in order to avoid noticeable interference (the transmission level is +5 nep, receiver level at maximum sensitivity is -3 nep and the difference between the receiver level and cross-talk level is 6.5 nep according to the norms accepted for long-distance communication equipment), the use of the same frequencies is possible only in a very large system on lines which are separated a considerable distance from each other.

The need of dividing the frequencies for all power systems as a whole and the need of the communication channels in any given line depend on the use of multigroup telephone installations. It is necessary to limit a given line to one communication channel so that all on a greater part of the line could be used for high-frequency communication purposes.

Technical-Economical Requirements of High-Frequency Communication Over Transmission Lines

Technical-economical requirements of high-frequency communication over electrical transmission lines are unusually high. The reliability of an electrical transmission line is much greater than a regular communication line. The stability of high-frequency communication over transmission lines is comparable to communication over underground cables.

The volume of capital outlay (equipment and assembly) on the construction of communication channels on 110-kv lines in 1941 was around 100,000 rubles, i.e., less than the amount needed for the construction of 50 ka of overhead communication lines. The level of the use of communication channels is limited by consumption of tubes and by periodic modifications.

Economic indexes of high-frequency installations can be increased significantly by multiple use of coupling condensers and the high-frequency stations. In certain cases, an insignificant saving in equipment outlay is offset by an extreme complication of the apparatus and subsequent lowering of its reliability. A compromise between the economical and exploitation interests should be maintained.

Transmission Systems

At the present time most of the high-frequency establishments operate with amplitude modulation and with the transmission of the carrier and both side bands. However, this transmission system is being displaced by more efficient ones from the viewpoint of distance and through the use of frequency spectrum transmission systems such as single side-band transmission with a suppressed carrier or a damped carrier, or a frequency-modulation system with a low modulation factor (6).

Comparative indexes of the various transmission systems are given in the following table.

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Transmission System	Band Width (kc)	Range (nep)	Remarks
Amplitude modulation; carrier and two side bands	5	b_0	The accepted modulation factor is equal to 100 percent
Amplitude modulation; carrier and single side band	2.5	$b_0 - 0.05$ $b_0 + 0.3$	Flat interferences Impulse interferences
Amplitude modulation; without carrier, single side band	2.2	$b_0 + 1.11$ $b_0 + 1.52$	Flat interferences Impulse interferences
Amplitude modulation; damped carrier, single side band	2.5	$b_0 + 0.87$ $b_0 + 1.22$	Flat interferences Impulse interferences
Frequency modulation; modulation factor is equal to 1	5	$b_0 + 1.25$ $b_0 + 1.4$	Flat interferences Impulse interferences

The selection of a system is determined by the nature of the enterprise which it will serve. For radio work, it is easier to become familiar with frequency modulation. For long-distance communication purposes, carrierless or a damped carrier system would be best.

However, it is not possible to shift immediately all the attainments of regular long-distance communications into an apparatus for power-system communication due to special problems and needs of such a change; also, special equipment would have to be constructed.

It would also be impractical to apply the technology of high-frequency communication over electrical transmission lines to ordinary long-distance communications. The realization of a high degree of automatic control of both these systems deserves special attention.

High-frequency communication along power transmission lines is ahead of regular long-distance communication lines in the utilization of higher frequencies. At the time when frequencies up to 50 kc were used over regular communication lines, a band from 50-150 kc was used on high-voltage lines. At the present time, frequencies up to 150 kc are used on regular communication lines, whereas a band up to 300 kc is used on the transmission lines. There are further possibilities of widening the range.

High-frequency communication channels basically appear as telemechanizations of the power systems. Usually multichannel high-frequency stations are used which permit 6-8 transmissions through carrier modulation with various "tonal" frequencies.

The frequencies of tonal channels are selected by the formula $f = 300 + n \cdot 120$ cycles, where $n = 1, 2, 3, \text{etc.}$ Such a frequency allocation imposes certain limits on the manipulation rate of the telemechanic instruments, which should be no higher than 20 impulses a second.

In the transmission of a carrier and both side bands, a six-channel high-frequency apparatus occupies a band of around 2 kc.

Telemeter stations are calculated for simplex communications (transmission only in one direction). A signal level increase over the interference level should not be more than 3 nep. For six-channel stations with a transmitter power of 10 watts, this corresponds to a transmission range of the order of 5 nep.

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Superimposed attenuation can be significantly increased by the transition to a single-band transmission system or to the transmission of groups of high frequencies, separated by 120 cycles. These systems need quartz stabilizers. They are very simple and make possible a range up to 6 nep.

Development of High-Frequency Communication Apparatus in TsNIEI of the Ministry of Electric Power Stations

In April 1941 the Technical Council of MEKP (People's Commissariat of the Electrical Industry) conducted conferences on high-frequency communication and high frequency shields, at which time the problems of the representatives of plants which developed and prepared equipment for high-frequency communication were accepted. Some of these were the Orgros, where work was done on exploitation, modernization, and development of new types of high-frequency shields and the IAT (Institute of Automatic and Telamechanics) of the Academy of Sciences, and others.

After the war, a part of these problems was placed in the communication laboratories of TsNIEI (Central Scientific Research Electrotechnical Laboratory) of the Ministry of Electric Power Stations. The absence of an industrial basis left the TsNIEI to occupy itself with low-level production of high-frequency receiver-transmitter shields and coupling filters which were developed in 1945-1946.

Recently, work was completed on a high-frequency communication system employing frequency modulation. This system was installed on one of the 220-kv lines of Mosenergo. A great deal of work is being conducted in the laboratories on the utilization of foreign equipment. In 1947 work was being conducted on various high frequency communications systems, telemeters, and shields, and also on separate components of high-frequency apparatus.

It will be necessary in the near future to organize an industrial base for the production of all instruments and rapid equipping of the power system with them.

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